Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Scientific Paper

Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v43n1e20220133/2023

MOISTURE LIMITS AND POTASSIUM CONCENTRATIONS IN THE SOIL SOLUTION FOR CULTIVATION OF LISIANTHUS (*Eustoma grandiflorum*) FERTIGATED UNDER PROTECTED ENVIRONMENT CONDITIONS

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KEYWORDS

irrigation, ceramic capsules, soil solution.

ABSTRACT

Lisianthus (*Eustoma grandiflorum*) has been attracting great interest due to the beauty of the colors of flowers, the firmness of stems, and postharvest durability. However, knowledge of lisianthus irrigation and fertigation has generally been based on recommendations from other countries. This study aimed to establish parameters for the rational management of lisianthus fertigation under a protected environment by determining the best lower limit of soil moisture, associated with the determination of the optimal potassium concentration to be maintained in the soil solution. The treatments consisted of five soil moisture limits for the start of irrigation and maintenance of five potassium concentrations in the soil solution, with four replications. Plots of 0.7 by 0.5 m were arranged in a completely randomized block design in a factorial scheme. The soil solution was monitored by measuring moisture as well as potassium (K^+) concentrations using a TDR100 reflectometer and solution extractors, respectively, during two cycles. The evaluated variables were the leaf area index, shoot fresh and dry matter, commercial yield, and average stem diameter. Lisianthus cultivation under the lower limit of soil moisture equal to 0.20 cm^3 cm^{-3} ensured the best results for all variables of commercial interest. No effect of potassium concentrations was observed on variables of commercial interest.

INTRODUCTION

In Brazil, the professionalization and commercial dynamism of floriculture are relatively recent phenomena. However, the activity already accounts for extremely significant numbers. Lisianthus (*Eustoma grandiflorum*), unlike what happens in other countries, is a crop that is still little studied in tropical climate conditions although it has great production and market potential (Almeida et al., 2021). The recent introduction of this species in the national market of ornamental plants has led to difficulties in its cultivation inherent to the scarcity of technical and scientific information about its production and management (Camargo et al., 2004).

Knowledge of lisianthus irrigation and fertigation, factors that have a high impact on the production and quality of stems and flower buds, have generally been based on empiricism, often resulting in the application of inadequate amounts of water and fertilizers. These actions have resulted in low crop yields, due to a deficit or excess soil moisture, changes in stem development due to a lack of potassium, waste of nutrients, and even soil salinization, which increase production costs (Backes et al., 2008; Petry et al., 2020).

This study aimed to evaluate the effect of soil moisture limits associated with the maintenance of potassium concentrations in the soil solution on the characteristics of growth, production, and quality of stems in two cultivation cycles of lisianthus fertigated and under protected environment.

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Area Editor: Edna Maria Bonfim-Silva
Received in: 8-18-2022
Accepted in: 11-28-2022

MATERIAL AND METHODS

Two cultivation cycles of lisianthus were carried out, the first from June 3 to October 1, 2015 (120 days), and the second from November 15, 2015, to January 24, 2016 (70 days) (Figure 1). The two cultivation cycles were carried out under a protected environment, located in an experimental area of the Department of Biosystems Engineering of the Luiz de Queiroz College of Agriculture, University of São Paulo, in the municipality of Piracicaba, SP, Brazil, at the geographic coordinates 22°42′ S and 47°38′ W, at an altitude of 546 m. According to the Köppen classification, the regional climate is Cwa, that is, a humid tropical climate with temperatures above 22 °C during the hottest month and below 18 °C during the coldest month.

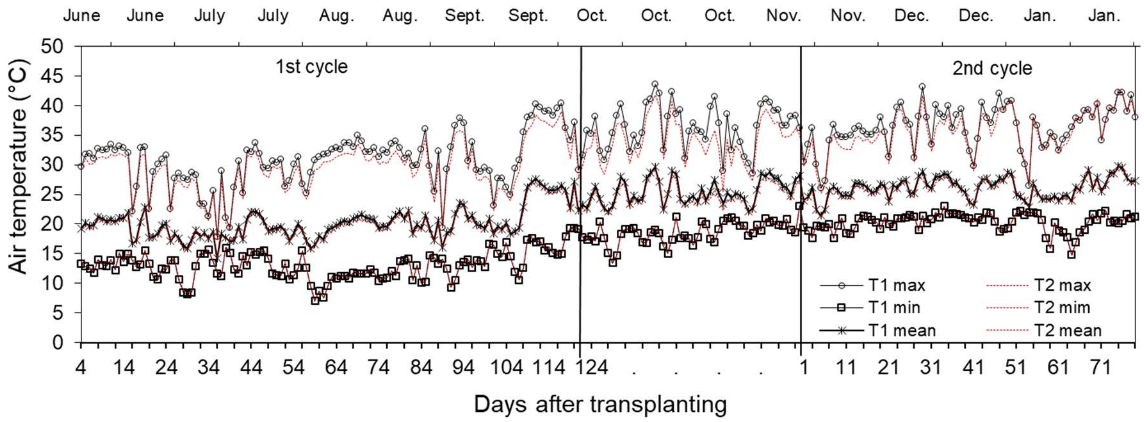

FIGURE 1. Maximum, mean, and minimum temperatures recorded inside the greenhouses over two cultivation cycles.

The experimental plots were allocated in two greenhouses with a 0.15-mm thick low-density polyethylene cover treated against the action of ultraviolet rays, forming an arc 6.40 m wide, 17.5 m in length, 3.7 m in height, and north-south orientation. The side and front walls are made with shading screens, with 50% radiation attenuation, and a 0.30-m baseboard built with reinforced concrete.

Five beds were built inside each greenhouse, comprising 10 experimental units each (Figure 1). The beds were 0.7 m wide, 0.50 m deep, and 15 m long, spaced at 0.40 m. Each bed had a drainage system consisting of plastic tarpaulin to waterproof the bottom, a corrugated drainpipe, 0.10-m layer of No. 1 gravel, and a geotextile blanket. Each experimental plot was 1.5 m long.

The soil was collected at a depth of 0.50 m from a profile classified as sandy Latossolo Vermelho-Amarelo (Oxisol). Representative composite samples were collected for soil chemical characterization. The following values were obtained: pH ($CaCl_2$) = 5.6, cation exchange capacity = 46.8 $mmol_c\ dm^{-3}$, base saturation = 57%, and K^+ concentration = 0.8 $mmol_c\ dm^{-3}$ (which is considered a low value for K^+). Analysis of the saturated paste extract revealed pH = 6.04, electrical conductivity = 0.38 dS m^{-1}, and potassium concentration = 7.02 mg L^{-1}.

Undisturbed and representative samples of two soil layers (0–0.15 and 0.15–0.30 m) were prepared to obtain soil water retention curves, which were adopted in irrigation management.

The treatments arranged in a 5×5 factorial consisted of five soil moisture limits to start irrigation (T1 = 0.20, T2 = 0.15, T3 = 0.13, T4 = 0.11, and T5 = 0. 09 $cm^3\ cm^{-3}$) and maintenance of five potassium concentrations in the saturated soil solution (K1 = 50, K2 = 100, K3 = 150, K4 = 200, and K5 = 250 mg dm^{-3}), controlled via fertigation, with four replications.

Retention curves were fitted to the van Genuchten model. The studied moisture limits corresponded approximately to tensions equal to 12, 25, 40, 70, and 120 kPa. The plots were arranged in two greenhouses, totaling 100 experimental plots (Figure 2), which were delimited with 0.2-mm thick PVC sheets, being constructed with 0.65 m wide, 1.45 m long, and 0.4 m deep.

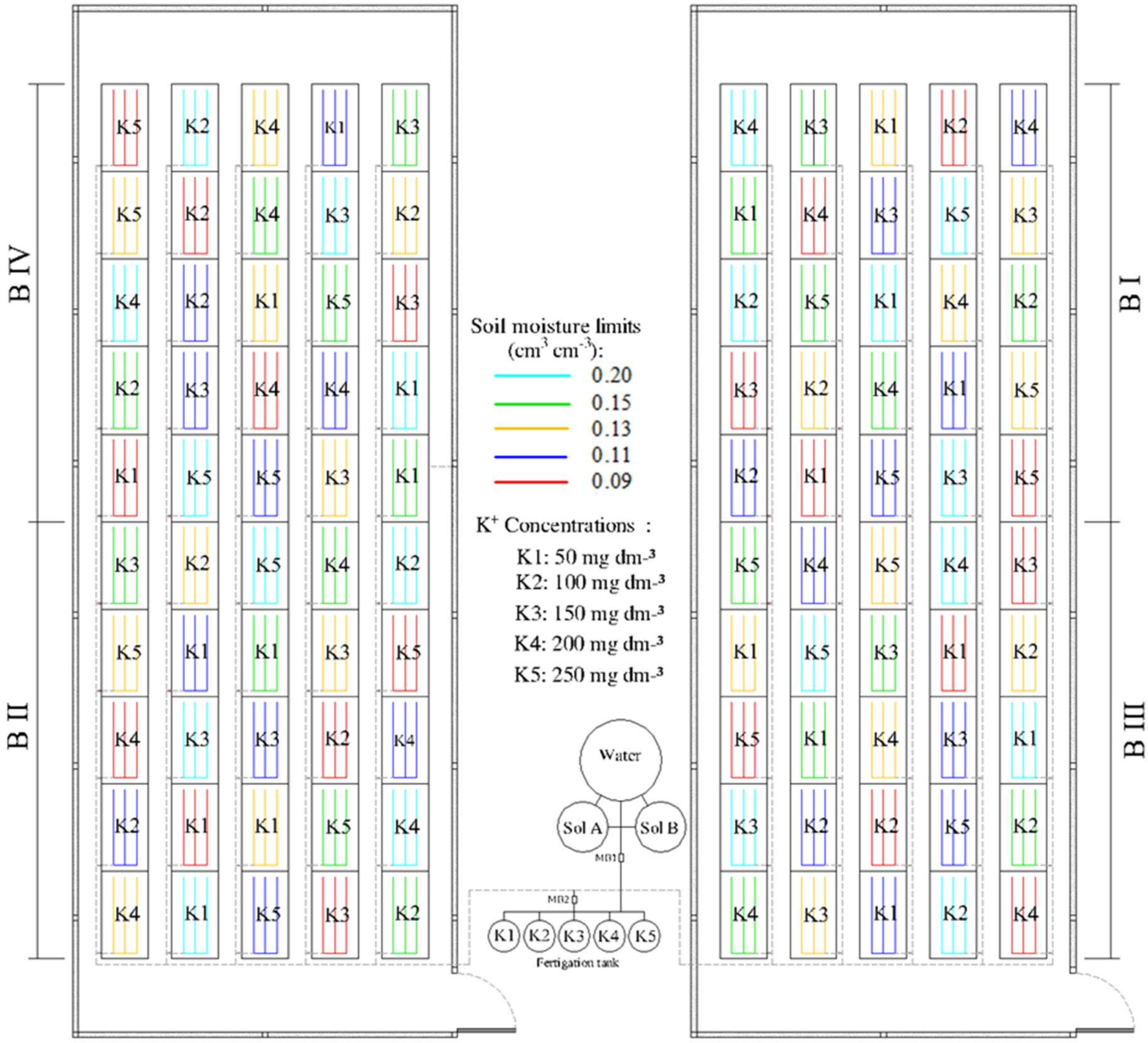

FIGURE 2. Sketch of the experimental area in two greenhouses.

A probe-TDR system was set up to allow the monitoring of the volumetric content of water in the soil (θ) at 25 points, using the equation by Topp et al. (1980). The system consisted of a TDR100 reflectometer (Campbell Scientific, Logan-Utah), which was driven by a Campbell Scientific CR10X datalogger, which also stored the data (Petry et al., 2020). K^+ concentration data were collected using solution extractors equipped with a porous capsule installed in the center of the plots. Air temperature data were collected using a Vaisala sensor (HMP45C-L12 - Campbell Sci.). This sensor was interconnected to a Campbell Scientific CR23 datalogger.

A drip irrigation system consisting of drip tubes with emitters spaced at 0.20 m, with an inner diameter of 16 mm and a nominal flow rate of 2.20 L h^{-1} for a service pressure of 250 kPa. The entire irrigation and fertigation system was composed of a reservoir tank for water supply with a capacity of 5000 L, reservoir tanks with a capacity of 500 L for fertigation, a 200-mesh disc filter, valves, pressure gauges, and solenoid valves. The coefficient of uniformity of distribution (CUD) measured was 95%.

The start of irrigation for each treatment was determined based on the lowest soil water content (θ_{low}). The applied depth was calculated to reach the maximum soil retention capacity (θ_{FC}). An effective root system depth of 0.3 m, a plot surface area of 0.94 m^2, and an application efficiency of 95% were also considered.

The initial potassium concentrations in the soil solution needed to be established before transplanting the crop and starting the fertigation management, during the two lisianthus cultivation cycles. The methodology consisted of the application of volumes of fertigation solution with different potassium concentrations but with equal concentrations for the other nutrients (Beneduzzi et al., 2022). For this purpose, the nutrient solution of Hoagland & Arnon (1950) diluted to 25% was adopted. Fertigation was also carried out in all irrigation. The soil was leached before the second cycle in order to restore the initial fertility conditions.

Vacuum application in the extractors, installed at 0.15 and 0.30 m, to monitor the potassium concentration in the soil solution, was performed using a vacuum pump. After 12 hours, potassium determination was performed by flame emission photometry. Soil moisture was checked at the time of vacuum application using a TDR probe. The standardized K^+ concentration values of the solution extracted by porous capsules were estimated from the dilution for moisture content of the paste, taken as standard. Different amounts of potassium chloride applied via fertigation were calculated so that the soil solution recovered the potassium concentrations initially established by the treatments at each fertigation. Fertigation was performed in all irrigations.

The variety used in the first cycle was Casablanca, belonging to the Pure White group, recommended for planting in the autumn-winter period. The adult plants belonging to this cultivar are about 0.70 m tall and complete a cycle of 120 days. The seedlings were purchased from a reputable nursery and the transplanting was carried out on May 30, 2015, when the seedlings had two pairs of definitive leaves. The population density was 64 plants per m^2, that is, a spacing of 0.125 × 0.125 m was used.

The greenhouses were cleaned and prepared for the second cycle after harvesting the plants. The plots were covered with double-faced mulching plastic and then a solution volume corresponding to 1.5 times the soil pore volume was applied with different K^+ concentrations.

The second cultivation cycle was carried out between November and February (spring-summer). For this period, the cultivation of the variety Excalibur, also from the Pure White group, was recommended. This variety is recommended for growing in seasons with higher temperatures and has growth and production characteristics similar to the Casablanca variety. However, during this period, the plants showed accelerated growth, and the harvest was carried out 70 days after transplanting (DAT), with the stand showing a smaller size compared to that of the first cycle.

The leaf area index (LAI) and the shoot fresh and dry matter were evaluated during the two cultivation cycles. In the first cycle, the plants were collected at 30, 60, 90, 110, and 120 DAT. In the second cycle, collections were performed at 30, 50, and 70 DAT. The stems were weighed using a semi-analytical balance (0.01-g precision) to determine the fresh mass and then packed in paper bags and dried in a forced-air circulation oven until reaching constant weight. The leaf area index (LAI) was determined during harvests in both cycles by dividing the values of the leaf area (cm^2) of each plant by the area occupied by it. The leaf area of each plant was determined by a LICOR area integrator.

The final harvest was performed when the stems had at least two open flower buds and at least 60% of the plants had this pattern. A total of 24 plants were harvested per plot to evaluate the production characteristics. Subsequently, the stems were sent to the laboratory for the evaluation of the mean stem diameter and total and commercial production. Three out of the total stems harvested in each plot were sampled to verify the mean diameter from three measurements at equidistant points, using a digital caliper graduated in millimeters. The rest of the stems were used to make commercial bouquets, which were standardized to a length of 60 cm. The criterion according to which the bouquets of lisianthus should be formed with at least eight stems without damage and with a minimum total weight of 500 grams was adopted.

The data were subjected to basic assumptions for adequacy to the analysis of variance model through the application of the Shapiro-Wilk test to verify the normality of the distribution of residuals, and the Bartlet test for homogeneity of variances. The evaluated parameters were statistically analyzed using analysis of variance. Factors relating to potassium concentrations in the soil solution and moisture limits were analyzed by applying polynomial regression (linear and/or quadratic). The entire statistical procedure was performed in the R environment, version 3.01.

RESULTS AND DISCUSSION

Figure 1 shows the variations in the mean, maximum, and minimum temperatures recorded in the two cultivation cycles. In the first cycle, between June and September 2015, the maximum temperature ranged from 17.8 to 40.4 °C, the mean temperature ranged from 14.2 to 27.6 °C, and the minimum temperature from 7.0 to 20.3 °C. In the second cycle, carried out between November 2015 and February 2016, maximum temperatures were observed ranging from 26.0 to 43.1 °C, the mean temperature ranged from 21.4 to 29.7 °C, and the minimum from 14.8 to 23.1 °C. Mean daily air temperatures outside the greenhouses ranged from 15.3 to 27.8 °C in the first cycle and 23.6 to 29.6 °C in the second cycle.

The minimum air temperature profile (Figure 1) shows a trend of increasing values from one cycle to the other. In the first cycle, 76.4% of the days had minimum temperatures below 15 °C, while in the second cycle, 66.3% of the days had minimum temperatures above 20 °C.

Figure 3 shows the mean volumetric soil water content profiles recorded during the first and second cultivation cycles for each studied moisture limit. Potassium concentrations did not affect the frequency of irrigation.

During the first cycle, 10, 6, 5, 5, and 5 irrigations were performed, on average, every 6, 10, 12, 12, and 12 days, when moisture limits of 0.20, 0.15, 0.13, 0.11, and 0.09 $cm^3\ cm^{-3}$ were adopted, respectively. Treatments with soil moisture limits of 0.11 and 0.09 $cm^3\ cm^{-3}$ showed no differences in the frequency of irrigation compared to the treatment with a moisture limit of 0.13 $cm^3\ cm^{-3}$, showing that the amount of water actually available below this moisture value is very small in the studied soil.

Furthermore, the frequency of irrigation of the first cycle in the treatment corresponding to the moisture limit of 0.20 $cm^3\ cm^{-3}$ (from 70 DAT) increases and the interval between irrigations decreases to three days as a result of the higher water demand of the crop, which was in an accelerated growth phase.

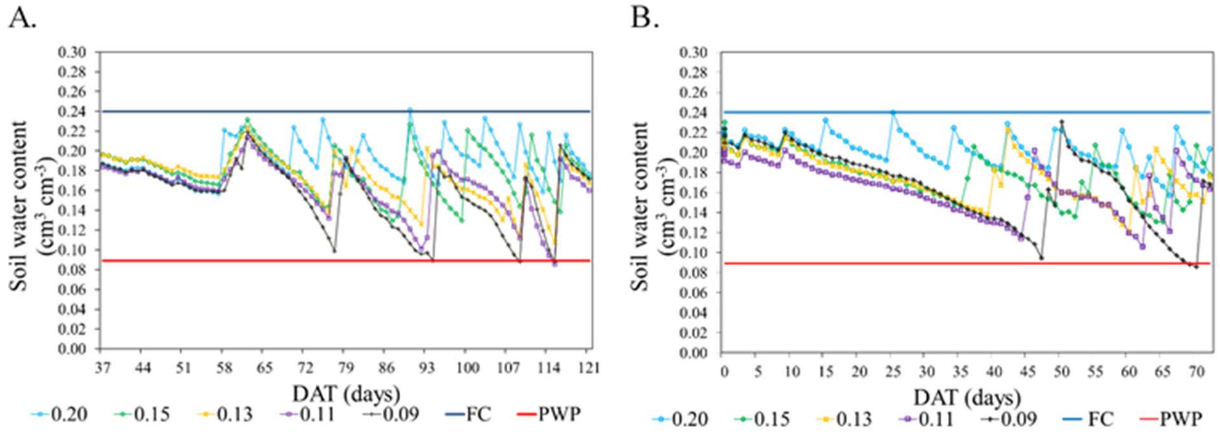

FIGURE 3. Mean volumetric soil water content profiles for different moisture limits throughout the first (A) and second (B) lisianthus cultivation cycles.

Regarding the second cycle, treatments with limit moistures equal to 0.20, 0.15, 0.13, 0.11, and 0.09 cm^3 cm^{-3} resulted in mean intervals between irrigations of 7, 11, 14, 17, and 23 days respectively. A total of 7, 3, 3, 3, and 2 irrigations were carried out in the mentioned plots.

As in the first cycle, the profiles that relate the variation in volumetric water content with time clearly show the pace of water consumption by the crop according to the stages of development. In addition, they allow the identification of the exact time when the irrigation was performed, as well as the quantification of the applied depth (Almeida et al., 2021). Therefore, the use of the TDR coupled with the data acquisition system (datalogger) allowed not only to obtain data related to the exposure of the lisianthus crop to critical levels of soil moisture, which would not be possible with the use of tensiometers, but also enabled the recording of instantaneous variations in soil moisture. Mounzer et al. (2006), Andrade Junior et al. (2022), and Costa et al. (2018) reinforce that precise and continuous monitoring of variations in soil water content in the laboratory in a greenhouse or the field is important means of investigating water consumption by plants and providing efficient bases for irrigation management.

The accounting of the accumulated irrigation depths for the treatments according to the studied moisture limits showed that the different potassium concentrations in the soil solution provided no expressive differences regarding the water consumption of the lisianthus crop during the two cultivation cycles. The first cycle presented a higher total water consumption, that is, 354.20 mm for the entire cycle (120 days) or 2.95 mm d^{-1} on average for treatments with moisture limits of 0.20 cm^3 cm^{-3} (Table 1). On the other hand, treatments with lower limit moistures had the lowest consumption, that is, 280.06 mm for the total cycle or 2.33 mm d^{-1} on average. The second cycle showed a similar daily water consumption, i.e., 210.95 mm for the total cycle (70 days) or 3.01 mm d^{-1} on average for treatments with moisture limits of 0.20 cm^3 cm^{-3}. In contrast, treatments with lower limit moistures showed the lowest consumption, that is, 135.20 mm for the total cycle or 1.93 mm d^{-1} on average. Thus, the second cycle, despite having occurred during spring and summer, provided water consumption similar to the first one for treatments that were more irrigated. This fact is possibly due to the smaller size and smaller leaf area observed during the second cycle.

TABLE 1. Irrigation depth applied according to the established minimum humidity limits, for each of the two cycles.

Lower moisture limit (cm^3 cm^{-3})	**First cycle**	**Second cycle**
0.20	350.20	210.95
0.15	320.71	173.82
0.13	300.88	168.41
0.11	295.05	142,49
0.09	280.06	135,20

The mean values of the leaf area index (LAI) analyzed as a function of moisture limits at 110 DAT (Figure 4) decreased linearly ($p<0.01$) as the limit moisture values decreased in both cycles. Thus, a reduction in LAI values of around 9.19, 11.48, 14.02, and 17.48% for limit moistures of 0.15, 0.13, 0.11, and 0.09 cm^3 cm^{-3}, respectively, was observed relative to the moisture of 0.20 cm^3 cm^{-3} in the first cycle and 7.12, 9.71, 11.01, and 13.08% in the second cycle.

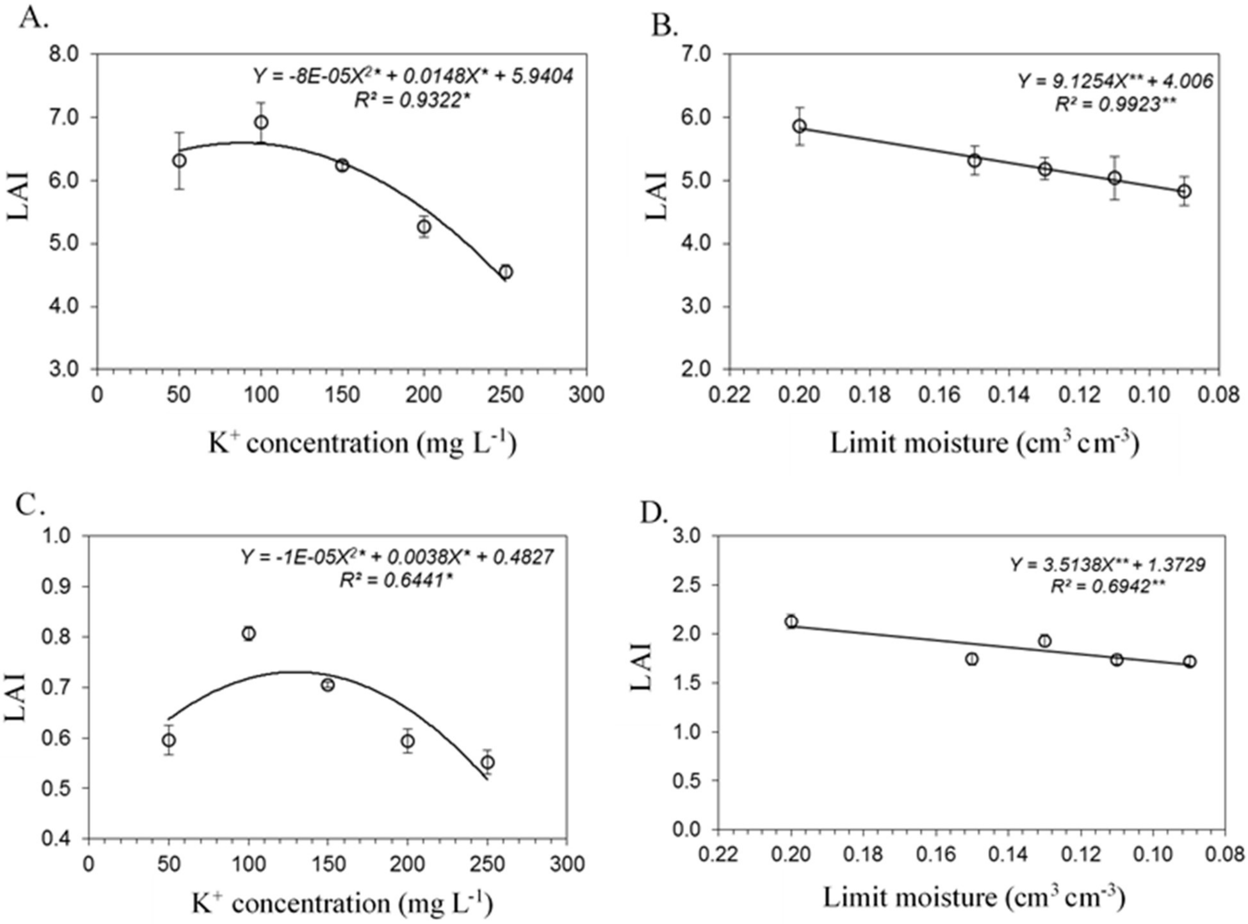

FIGURE 4. Leaf area index (LAI) as a function of potassium concentration in the soil solution (A and C) and limit moisture for starting irrigation (B and D), with A and B for the first cycle and C and D for the second cycle.

Potassium concentration in the soil solution significantly influenced the leaf area index. LAI fitted the second-degree polynomial model in both cycles, having a maximum point for concentrations from 50 to 100 mg L^{-1} of K^+ in the first cycle and 100 from 150 mg L^{-1} in the second cycle. According to Kim et al. (2017), Masouleh & Sassine (2020), Silva et al. (2020), and Beneduzzi et al. (2022), the ideal concentration of a nutrient in the soil solution for a certain species can be significantly influenced by the season of the year.

Two possible explanations stand out regarding the reduction in LAI due to higher potassium concentrations in the solution. The first one refers to the increase in the electrical conductivity of the soil solution due to an increase in the concentration of KCl, a salt used as a source of potassium and characterized by having a high salt index, in addition to the presence of the chloride ion (Cl^-), which is potentially toxic to a large number of ornamental species. According to Silva et al. (2018), high concentrations of some fertilizers can compromise the absorption of water and nutrients as a result of the decrease in the osmotic potential of the solution near the rhizosphere. Even though classic symptoms of the salinity effect were not observed in lisianthus plants, the reduction in LAI and, consequently, leaf surface, can be justified by the plant's attempt to reduce water loss as a strategy to adapt to the osmotic stress condition.

The second possible explanation may be related to the higher potassium concentration available to the plant, which can become more efficient in photosynthetic processes, not requiring a large leaf surface. Costa et al. (2018) and Miranda et al. (2019) reported that leaf area values are just large enough to be able to transfer excess sensible energy into latent heat via leaf transpiration, in combination with a well-developed root system and correctly supplied with water, would help to maintain high leaf transpiration rates.

The effect of the moisture limits on the fresh and dry matter of plants was evident at the end of the first and second cycles, with a significant negative linear response ($p<0.05$) for these variables as a function of the limit moisture values for irrigation (Figure 5). For the first cycle, the means of fresh matter registered immediately after the final harvest in plants submitted to the limit moisture of 0.20 $cm^3\ cm^{-3}$ presented significantly higher mean values in the order of 6.33, 6.79, 9.81, and 12.77% relative to plants submitted to limit moistures of 0.15, 0.13, 0.11, and 0.09 $cm^3\ cm^{-3}$, respectively.

The mean values of fresh matter ranged from 54.10 to 32.04 g in the second cycle, resulting in a decrease in the fresh matter in the order of 41% for plants irrigated under the limit moisture of 0.09 $cm^3\ cm^{-3}$ compared to the plants with higher water availability.

Almeida et al. (2016) evaluated the development of lisianthus under different light transmission meshes in a protected environment in Piracicaba, SP, Brazil, and obtained plants with stem fresh matter ranging from 41.30 to 60.62 g.

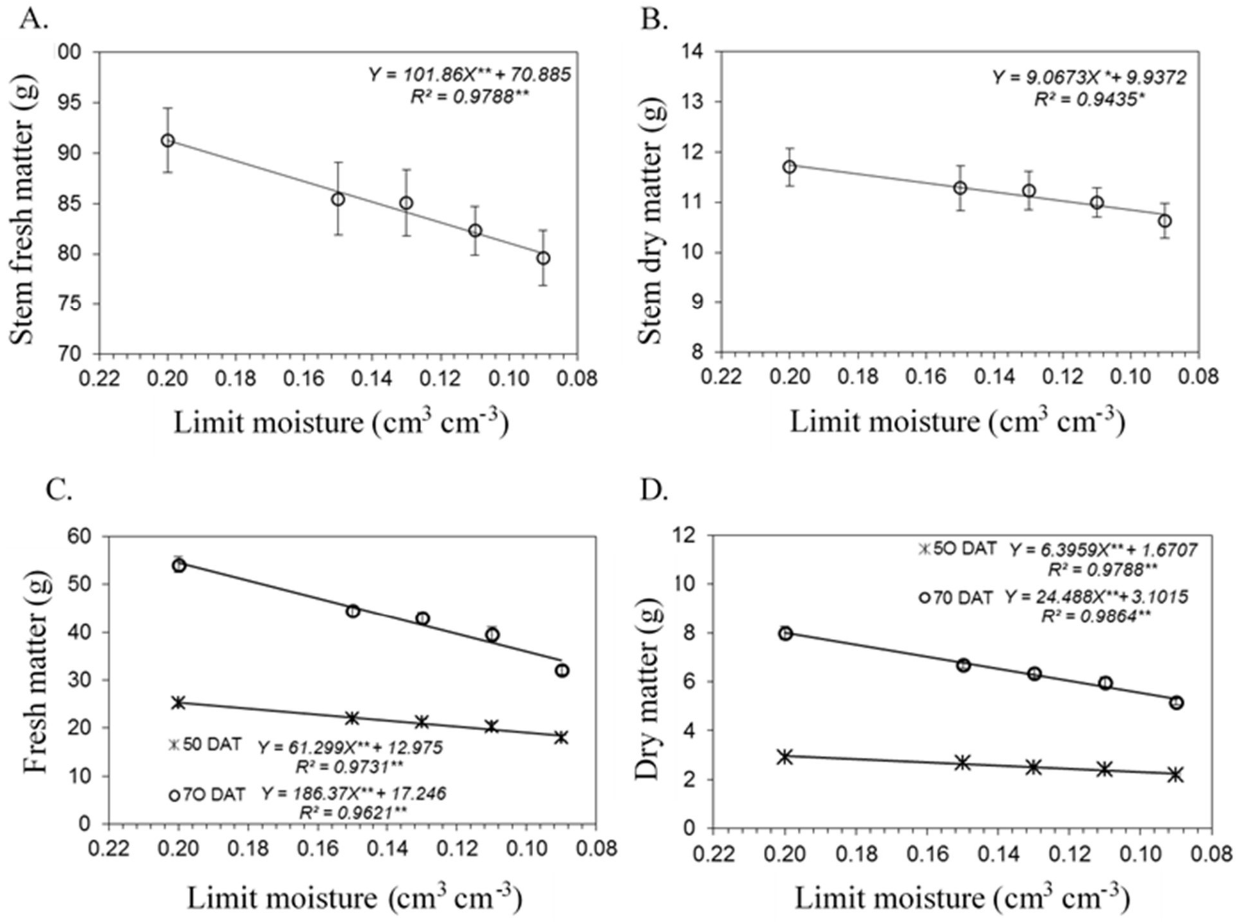

FIGURE 5. Fresh (A and C) and dry (B and D) matter of lisianthus plants as a function of the limit moisture for starting fertigation, with A and B for the first cycle at 120 DAT and C and D for the second cycle at 50 and 70 DAT.

All mean values of plant fresh mass were considered commercially viable. Even the plants submitted to the lowest limit moisture levels produced enough fresh matter to form bouquets with the minimum number of stems that met commercial standards. Moreover, the management of potassium concentration in the soil solution did not significantly influence the variables of production and quality of stems in both cycles.

Backes et al. (2007) studied different nutrient solutions in the hydroponic cultivation of cut lisianthus and found mean values of shoot fresh matter ranging from 105.28 to 138.96 g. In contrast, Alves et al. (2015) studied the production and postharvest of three varieties of lisianthus under a protected environment condition in a period and duration of the cycle similar to the one conducted in the first cycle of the present study (120 days) and obtained mean values of fresh matter of 84.5, 73.6, and 55 g for the varieties Bolero, Borealis, and Echo, respectively.

The main variables of commercial interest and yield showed a significant negative linear response ($p<0.01$) as a function of the reduction in limit moisture values (Figure 6). Stems that met the minimum quality standards required by the cut floristry market were obtained at the end of the first cultivation cycle. This fact demonstrates the need for rational management of soil moisture when trying to obtain quality stems with satisfactory yields. The limit moisture of 0.20 $cm^3\ cm^{-3}$ provided commercial yield and diameter of the upper stems by 31.6 and 11.8% compared to the means of the other treatments, respectively, although the effect on the stem diameter was not significant. This fact reinforces the assumption that the lisianthus crop, despite being originally from regions with desert characteristics, responds satisfactorily to higher irrigation frequency, which ensured higher production (5.10 $kg\ m^{-2}$) and better quality flower stems for the highest limit moisture.

In the second cycle, plants irrigated with the moisture of 0.20 $cm^3\ cm^{-3}$ provided stems with mean diameters of up to 7.7, 9.3, 12.69, and 16.94% higher than the other treatments. The mean stem diameter associated with the highest mean weight, allowing their standardization for the formation of the commercial bouquet, provided a commercial yield of 2.56 $kg\ m^{-2}$ for soil moisture of 0.20 $cm^3\ cm^{-3}$, which is 12.68, 18.43, 27.05, and 44.20% higher than the yields observed for the other treatments.

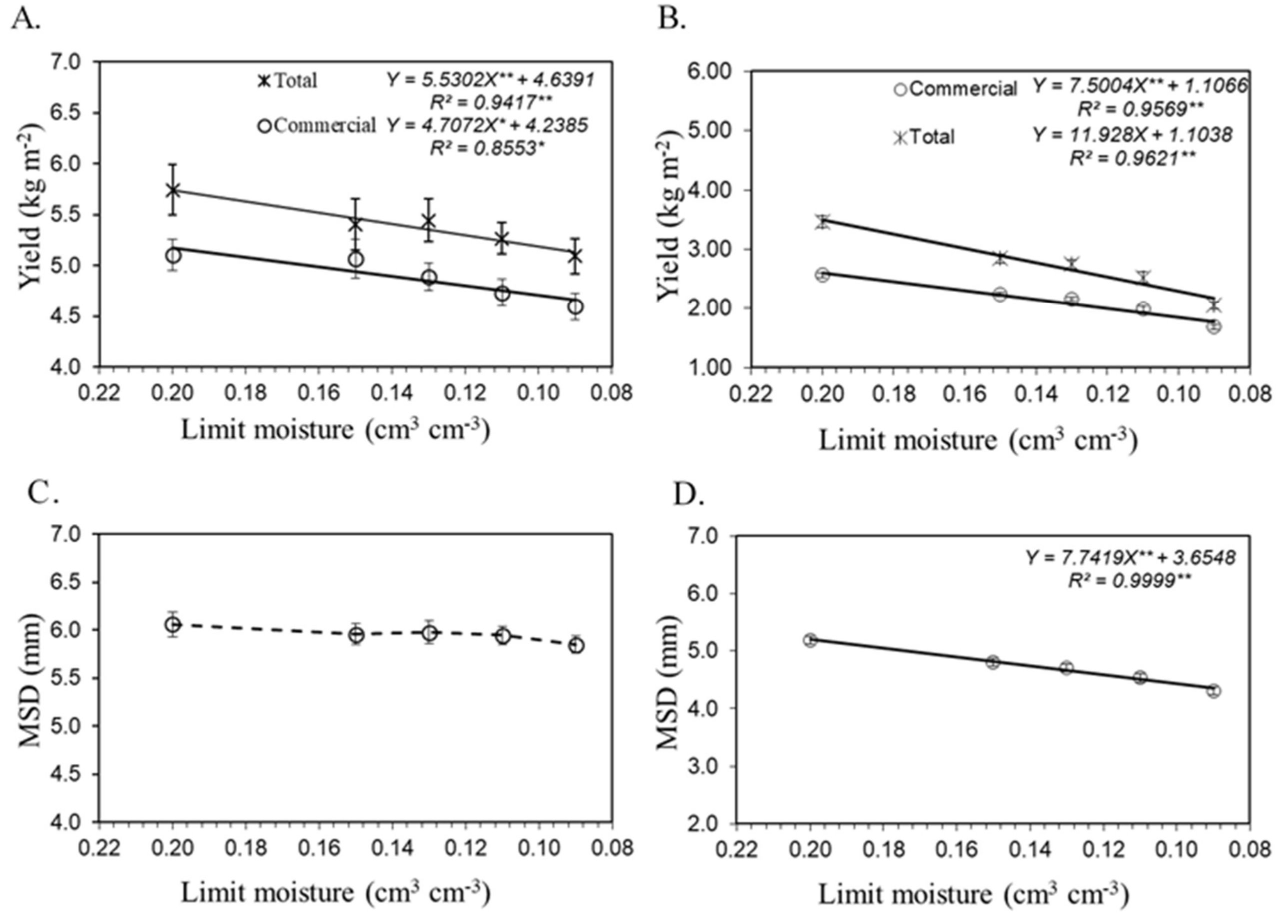

FIGURE 6. Total and commercial yield (A and B for the first and second cycles, respectively) and stem diameter (C and D for the first and second cycles, respectively) as a function of the limit moisture for starting irrigation.

The comparative analysis between the two cultivation cycles of the present study, the first between the beginning of June and the end of September (autumn-winter) and the second between November and the beginning of February (spring-summer), showed marked differences in the microclimatic conditions to which the lisianthus crop was submitted. There was an increase in minimum temperatures, as well as night temperatures, associated with a longer photoperiod of the second cycle, leading to a decrease in the lisianthus stand in this cycle.

The variety Casa Blanca completed its cycle at 120 DAT (autumn-winter) and showed a maximum commercial yield equal to 5.10 kg m^{-2} under the microclimatic conditions of the greenhouses during the first cycle. In the second cycle (spring-summer), the variety Excalibur completed its cycle at 70 DAT despite being recommended for higher temperatures and presented a maximum commercial yield equal to only 2.56 kg m^{-2}.

CONCLUSIONS

a – Despite being a crop originating in an environment with desert characteristics, lisianthus cultivated in a protected environment responds satisfactorily well to maintaining soil moisture at high levels. Irrigation carried out under a lower moisture limit equal to 0.20 cm^3 cm^{-3}, which corresponded to a tension of 12 kPa, showed the best growth and production characteristics in qualitative and quantitative terms.

b – Characteristics of growth, yield, and quality of flower stems of the lisianthus crop were not influenced by the potassium concentrations imposed in the soil solution, except for the leaf area index. Further experiments could test a wider range of potassium concentrations.

c – The use of TDR to monitor soil moisture and porous capsule extractors to maintain K^+ of the soil solution enabled satisfactory management of the solution throughout the crop cycle, allowing precision in calculating the water depth and moment of irrigation of the fertigated lisianthus crop under a protected environment.

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